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US-A- 4 006 968

IBM TECHNICAL DISCLOSURE BULLETIN, vol. 29, no. 11, April 1987, pages 4838-4839, Armonk, New York, US; "Backlighting for liquid crystal display"

PATENT ABSTRACTS OF JAPAN, vol. 8, no. 228 (P-308)[1665], 19th October 1984; & JP-A-59 109 028

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Description

This invention relates generally to illumination systems for display devices and particularly to such a system for a liquid crystal display device capable of producing color television pictures.

Liquid crystal display devices used to produce color displays typically require backlighting to achieve the image brightness required for viewing in daylight ambient conditions. Existing illumination systems frequently employ a diffuser just before the liquid crystal array in order to smooth the spatial distribution of light from the lamp. Such a diffuser causes the light entering the liquid crystal array to be spread over a wide range of angles. However, it is known that the contrast of the display can be improved if the angular range of the entering light rays in one azimuth is confined to 15 degrees or less from the perpendicular to the array. There is no restriction for ray components having the orthogonal azimuthal orientation. One existing system uses parabolic reflectors with light sources at the foci of the reflectors to provide partially collimated light. Various lens systems are employed to further control the angles over which the light is incident on the liquid crystal cells. Another scheme for back illuminating the liquid crystal cells of a display device includes a solid light conduit which is illuminated at one end, and which has prisms along a second surface to release the light in a controlled manner to the liquid crystal cells.

In a liquid crystal display device capable of producing a full spectrum of colors, each pixel of the display is composed of a triad of pixel elements. Each of the pixel elements is a liquid crystal cell which transmits one of the primary light colors. The liquid crystal cells themselves do not produce color, and accordingly each cell must be associated with a filter of the appropriate light transmission capability. Also, the light provided to the liquid crystal cells must be polarized because of the intrinsic functional characteristics of the liquid crystal cells. A substantial percentage of the illumination, as much as 85%, is lost to the filters and polarizers. Accordingly, the illumination efficiency of liquid crystal display devices is very low, and the illumination source is called upon to produce a significantly higher intensity of light than is actually needed to illuminate the display screen. As a result, a very large percentage of the available energy of the display device is consumed by the illumination source. This is a particularly posing disadvantage in portable display devices because it results in a substantial reduction in the lifetime of the power source and, thus, in the viewing time of the display.

For these reasons there is a need for a more efficient illumination system for display devices. The present invention fulfills this long felt need.

One type of illumination system for a display device, which includes a plurality of lenslets, is disclosed by IMB Technical Disclosure Bulletin, vol.29, no.11, April 1987, pages 4838-4839.

In accordance with the present invention, an illuminating system for a display device comprises a matrix of substantially circular lenslets arranged so as to provide partially collimated light; a light box arranged to provide uncollimated light to said lenslets, said light box being internally highly and diffusely reflective, said light box housing at least one light source arranged in the proximity of one edge of said light box, said light box having a light opaque reflector coincident with said lenslets, said reflector including a matrix of light transmissive apertures centered with respect to the optical axes of said lenslets so as to individually transmit uncollimated light from said light box to said lenslets; said apertures having a radius substantially less than the radius of said lenses; characterized by first, second and third interference filters sequentially arranged in said apertures in a repetitive pattern, said first filters transmitting the first (R) primary light color and reflecting the second (G) and third (B) primary light colors back into said box, said second filter transmitting the second primary light color and reflecting the other two primary light colors back into said box, and said third filters transmitting the third primary light color and reflecting the other two primary light colors back into said box.

According to another aspect of the present invention, an illuminating system for a display device comprises a plurality of juxtaposed elongated lenslets having elliptical cross section arranged substantially parallel to each other so as to provide partially collimated light; a light box arranged to provide uncollimated light to said lenslets, said light box being internally highly and diffusely reflective, said light box housing at least one light source arranged in the proximity of one edge of said light box, said light box having a light opaque reflector coincident with said lenslets, said reflector including a plurality of elongated light transmissive slots arranged substantially parallel to said lenslets and centered with respect to the optical axes of said lenslets so as to individually transmit uncollimated light from said light box to said lenslets; characterized by first, second and third differently coloured filters sequentially arranged in said slots in a repetitive pattern.

In the drawings:

FIGURE 1 is a broken-away cross-section of a simplified showing of a liquid crystal display device incorporating a preferred embodiment of the invention.

FIGURE 2 is a portion of a first preferred embodiment.

FIGURE 3 is a portion of a second preferred embodiment.

FIGURE 4 shows the relationship of the elongated lenslets, the color filters, and the pixel elements for the preferred embodiments of FIGURES 2 and 3.

FIGURE 5 is a portion of a third preferred embodiment.

FIGURE 6 is a portion of a fourth preferred embodiment.

FIGURE 7 is useful in understanding how the cross sectional configuration of the elongated lenslets is selected.

In FIGURE 1, a display device 10 includes a light box 11, the inside surfaces of which have very highly and diffusely reflectivities. Light sources, such as 12a and 12b, are arranged along two of the edges of the light box 11 and provide the back illumination needed for the screen of the display device. The light sources 12a and 12b preferably are tubular and extend the full length of the light box 11, substantially parallel to the sides thereof. However, different types of light sources can also be used. A reflector 13 is included in the light box 11 and also has a highly and diffusely reflective surface. As described below with respect to FIGURES 2, 3 and 5, the reflector 13 includes a plurality of slots, or apertures, which transmit light from the light box 11 to the viewing screen of the display device 10. A lens 14, which is described in detail below with respect to FIGURES 2, 3 and 6, is supported by the reflector 13, and can be integral therewith. A plurality of liquid crystal cells (pixel elements) 16R, 16G and 16B are supported by the lens 14. Each pixel of the display screen includes one of each of the cells 16R, 16G, 16B. Details of the pixel elements 16R, 16G, 16B are presented below with respect to FIGURES 4 and 5.

In FIGURE 2, the lens 14 is a lenticular lens array formed of a plurality of longitudinal lenslets 17 which are juxtaposed and formed into an integral unit having a smooth surface 18. The lens 14 can be made of glass or preferably of molded plastic. The reflector 13 is affixed to the smooth surface 18 and includes a plurality of slots 19 having widths S. The slots 19 are centered about the optical axes 21 of the lenslets 17. The lens 14 has an index of refraction n which, as described below with respect to FIGURE 7, is instrumental in determining the cross-sectional configuration of the lenslets 17. The depth H of the light box 11 is large with respect to the width S of the slots 19. Also, the internal surfaces of the light box 11, including the surface of reflector 13 which faces light box 11, are highly and diffusely reflective. Accordingly, a relatively uniform light intensity with approximately random directional distribution is obtained throughout the light box 11, and each of the slots 19 transmits substantially the same intensity of light. The light sources 12a and 12b are arranged outside the area of the lens 14 to enhance the uniformity of light provided to the slots 19.

FIGURE 2 shows light rays 22a through 22i, in the plane of the FIGURE, from a number of random directions representative of random light within the light box 11. As the light rays pass through the slots 19, they change directions relative to the normal surface 18 of the lens 14. The relationship between the angles θ and ϕ from the normal, for a material having an index of refraction n, is given by Snell's Law. Approximating the index of refraction of air as unity, the angular relationship is:

$$\sin(\theta) = n \sin(\phi).$$

Letting the angle θ have a maximum value of 90° yields the maximum angle ϕ of:

$$\phi\text{max} = \arcsin(1/n). \qquad (1)$$

From equation (1) it can be calculated that all the light passing through the slots 19 into the lens 14 is confined within the angles $+/- \phi$ max inside the material of which the lens 14 is composed. As an example, if the lens 14 is composed of polycarbonate, which has a reflective index of 1.6, the maximum internal angles become ±38.7°. The slots 19 are narrow compared to the thickness t of the lens 14; accordingly, light exiting upwardly from the smooth surface 18 is confined between the correspondingly narrow pair of angles $+/- \alpha$. Again using polycarbonate as an example, and taking the slot width S to be 12% of the thickness t, extreme rays from the slot edges will pass through the center of the lens 14 at an internal angle β of about ±4.1°. The external angle α for the same rays leaving the lens 14 is increased according to Snell's Law and becomes about ±6.60°. This angular spread is well within the needs of liquid crystal display systems in the narrow direction of the crystals.

In FIGURE 3, the slots 19 are displaced from the surface 18 of the lens 14 into the light box 11. The slots 19 are again centered on the optical axes 21 of the lenslets 17. The edges 23 of the slots 19 are disposed at an angle γ with respect to the optical axes 21 of the lenslets 17. The construction of the lens 14 shown in FIGURE 3 permits all the crucial dimensional relationships between the slots 19 on one side of the lens and the lenslets 17 on the other side of the lens to be established during the forming of the lens. For example, hot pressing or molding methods can be used to form both sides of the lens 14 simultaneously.

In the FIGURE 3 embodiment, reflector 13 is formed by depositing a highly and diffusely reflective material onto the surface 18 between the slots 19. During the deposition process it is possible that the reflective material will also coat the slots 19. If this occurs, the reflective material can easily be removed from the slots 19 by abrasion or polishing methods. Advantageously, the slots 19 are accurately positioned with respect to the optical axis 21 of the lenslet 17 using low-cost, well-known fabrication techniques.

In FIGURE 4, red, green and blue filters 24R, 24G and 24B, respectively, are arranged between each of the lenslets 17 and the liquid crystal cells (pixel elements) 16R, 16G, 16B. The filters 24R, 24G, 24B can be either absorptive or interference filters. Accordingly, in the FIGURE 4 embodiment, each of the lenslets 17 provides partially collimated light, that is, light confined within a narrow transverse angle, for each pixel composed of a triad of pixel elements 16R, 16G and 16B. Components of the light, obtained by projecting the exiting rays onto the x-z plane, are partially collimated within the range of angles $+\alpha$ to $-\alpha$. Components of the light in the orthogonal direction, obtained by projecting the exiting rays onto the y-z plane, are not subject to collimation by the elongated cylindrical lenslets 17.

FIGURE 5 is an embodiment which permits elimination of the filters 24R, 24G and 24B of FIGURE 4. Dielectric film interference filters 26R, 26G and 26B are sequentially arranged in the slots 19. The interference filter 26R transmits red light to the lens 14a and reflects green and blue light back into light box 11. Similarly, interference filter 26G transmits green light to the lens 14a and reflects red and blue light back into the light box 11. Interference filter 26B transmits blue light and reflects red and green light. The interference filters 26R, 26G and 26B are arranged in a repetitive pattern along an axis extending perpendicular to the longitudinal axis of the lenslets 17a. The interference filters 26R, 26G and 26B are longitudinal and extend the full length of the lenslets 17a and the slots 19. The lenslets 17a have a diameter D which is substantially equal to the width W of the pixel elements 16R, 16G and 16B. Accordingly, each lenslet 17a provides partially collimated light to the pixel elements for one primary light color. This is different from the embodiment of FIGURE 4 where each of the lenslets 17 provides collimated light to three pixel elements. Because the interference filters 26R, 26B and 26G transmit only one color of light, a significantly higher light output to the screen is achieved because the unselected colors are reflected back into the light box 11 and eventually exit from a slot associated with a filter having the proper light transmission capability, after a slight absorption because of the additional reflections within the light box 11.

In the embodiments described with respect to FIGURES 2 to 5, the lenslets 17 and 17a are elongated cylinders having a constant cross-sectional configuration and, accordingly, confine light in only one direction. FIGURE 6 is an embodiment which confines light in orthogonal directions, concentrating the light close to the axes of the lenses. In the FIGURE 6 embodiment, the lenslets 17 and 17a of the other embodiments are replaced by spherical lenslets 27 arranged in a matrix parallel to the horizontal and vertical axes of the viewing screen. Circular apertures 28 are centered with the central and optical axes 29 of the lenslets 27. The radii of the apertures 28 are limited by the same off axis light ray considerations that limit the slot widths in the previous embodiments. Consequently, the maximum aperture diameters are equal to the maximum slot widths for any particular thickness of the lens 14b. Because the apertures 28 constitute a much smaller fraction of the total area of the walls of the light box 11 than do the slots 19 in the other embodiments, the required light intensity within the light box 11 for a given transmitted light flux at the screen is greater for the circular aperture embodiment than for the slotted embodiments. For similar reasons, because the light undergoes a greater average number of wall reflections before escaping through a circular aperture, the absorptive loss in the light box is larger for the circular aperture configuration.

FIGURE 7 shows a representative lens profile for a lens material having a refractive index of 1.6, the index of polycarbonate, a preferred material for the lenses 14, 14a and 14b. The origin of the coordinate system is taken on the optical axis at the surface 18 of the lens and at the center of slot 19. FIGURE 7 shows the radii r and r_o of the lens at various angles from the optical axis 21. The profile is not complicated and dies having a multiplicity of parallel grooves with the appropriate contour can easily be fabricated to form the lens 14 by either hot pressing or by molding.

Letting the angle between the tangent to the lens and a line through the origin be represented by γ, as shown in FIGURE 7, and letting r_o represent the thickness of the lens along the optical axis, the lens contour is given by the equation:

$$r = r_o e^{-\int_o^{\delta} \tan(\gamma)\, d\delta} \qquad (2)$$

where the relationship between the angle, γ, and the internal refractive angle, δ, is given by:

$$\delta = \arcsin(n \sin(\gamma)) - \gamma. \qquad (3)$$

Equations (2) and (3) are solved by a simple ellipse of the form:

$$r = r_o (n-1)/(n-\cos(\delta)) \qquad (4)$$

where the eccentricity of the ellipse is 1/n.

This contour formula is rigorously correct only for very narrow slots. However, since the liquid crystal cells can tolerate off-axis light ray directions up to approximately 15 degrees, these formulas are applicable for slot widths up to approximately 12 percent of the lens thickness t, as was used in the above example. The cross-sectional configuration of the lenslets 17 and 17a therefore is that of an ellipse. However, a circular profile is a special case of an elliptical profile and is an acceptable configuration for the lenslets. Other lens profiles are also acceptable; for example, a parabolic or a hyperbolic profile can be used depending upon the angular concentration requirements. Accordingly, as used herein, the term "generally elliptical" is to be construed as encompassing any curved profile which concentrates the light rays onto the pixel elements.

Claims

1. An illumination system for a display device comprising a matrix of substantially circular lenslets (27) arranged so as to provide partially collimated light; a light box (11) arranged to provide uncollimated light to said lenslets, said light box being internally highly and diffusely reflective, said light box housing at least one light source (12a, 12b) arranged in the proximity of one edge of said light box, said light box having a light opaque reflector (13) coincident with said lenslets, said reflector including a matrix of light transmissive apertures (28) centered with respect to the optical axes of said lenslets so as to individually transmit uncollimated light from said light box to said lenslets; said apertures having a radius substantially less than the radius of said lenses; characterized by first (26R), second (26G) and third (26B) interference filters sequentially arranged in said apertures in a repetitive pattern, said first filters transmitting the first (R) primary light color and reflecting the second (G) and third (B) primary light colors back into said box, said second filter transmitting the second primary light color and reflecting the other two primary light colors back into said box, and said third filters transmitting the third primary light color and reflecting the other two primary light colors back into said box.

2. The illumination system of claim 1, **characterized in that** said circular lenslets (27) form an integral lens (14b) having a smooth surface (18) facing said light box (11), and said reflector (13) is permanently affixed to said smooth surface.

3. The illumination system of claim 2, **characterized in that** said apertures (28) are displaced from said smooth surface (18).

4. The illumination system of claim 3, **characterized in that** the radius of said apertures (28) is less than approximately 15% of the radius of said lenslets (27).

5. The illumination system of any of claims 2 to 4, **characterized in that** said light source includes at least one elongated tube (12a, 12b) arranged substantially parallel to the edge of said light box (11) and outside of said integral lens (14b).

6. An illumination system for a display device comprising a plurality of juxtaposed elongated lenslets (17, 17a) having elliptical cross section arranged substantially parallel to each other so as to provide partially collimated light;
a light box (11) arranged to provide uncollimated light to said lenslets, said light box being internally highly and diffusely reflective, said light box housing at least one light source (12a, 12b) arranged in the proximity of one edge of said light box, said light box having a light opaque reflector (13) coincident with said lenslets, said reflector including a plurality of elongated light transmissive slots (19) arranged substantially parallel to said lenslets and centered with respect to the optical axes of said lenslets so as to individually transmit uncollimated light from said light box to said lenslets;
characterized by first (26R), second (26G) and third (26B) differently coloured filters sequentially arranged in said slots in a repetitive pattern.

Patentansprüche

1. Beleuchtungssystem für eine Anzeigevorrichtung, die umfaßt: eine Matrix aus im wesentlichen kreisförmigen Linsenelementen (27), die angeordnet sind, um partiell paralleles Licht bereitzustellen; einen zur Lieferung von nicht-

parallelem Licht an die Linsenelemente angeordneten Lichtkasten (11), wobei der Lichtkasten im Innern hoch und diffus reflektierend ist, der Lichtkasten mindestens eine Lichtquelle (12a, 12b) enthält, die in der Nähe einer Kante des Lichtkastens angeordnet ist, der Lichtkasten einen mit den Linsenelementen zusammenfallenden Opaklichtwerfer (13) besitzt, wobei der Lichtwerfer eine Matrix von Licht übertragenden Öffnungen (28) besitzt, die in Bezug auf die optischen Achsen der Linsenelemente zentriert sind, um einzeln das nicht-parallele Licht von dem Lichtkasten zu den Linsenelementen zu übertragen; wobei die Öffnungen einen Radius besitzen, der wesentlich kleiner ist als der Radius der Linsen, **gekennzeichnet durch** erste (26R), zweite (26G) und dritte (26B) Interferenzfilter, die aufeinanderfolgend in den Öffnungen gemäß einem Wiederholungsmuster angeordnet sind, wobei die ersten Filter die erste (R)-Primärlichtfarbe übertragen und die zweite (G)- und dritte (B)-Primärlichtfarbe in den Kasten zurückreflektieren, die zweiten Filter die zweite Primärlichtfarbe übertragen und die anderen zwei Primärlichtfarben in den Kasten zurückreflektieren, und die dritten Filter die dritte Primärlichtfarbe übertragen und die anderen zwei Primärlichtfarben in den Kasten zurückreflektieren.

2. Beleuchtungssystem gemäß Anspruch 1, **dadurch gekennzeichnet**, **daß** die kreisförmigen Linsenelemente (27) eine einstückige Linse (14b) bilden, die eine gleichförmige Oberfläche (18) besitzt, die zu dem Lichtkasten (11) weist, wobei der Lichtwerfer (13) ständig an der gleichförmigen Oberfläche befestigt ist.

3. Beleuchtungssystem gemäß Anspruch 2, **dadurch gekennzeichnet, daß** die Öffnungen (28) gegenüber der gleichförmigen Oberfläche (18) versetzt sind.

4. Beleuchtungssystem gemäß Anspruch 3, **dadurch gekennzeichnet, daß** der Radius der Öffnungen (28) kleiner als ungefähr 15% des Radius der Linsenelemente (27) ist.

5. Beleuchtungssystem gemäß einem der Ansprüche 2 bis 4, **dadurch gekennzeichnet, daß** die Lichtquelle mindestens eine längliche Röhre (12a, 12b) umfaßt, die im wesentlichen parallel zu der Kante des Lichtkastens (11) und außerhalb der einstückigen Linse (14b) angeordnet ist.

6. Beleuchtungssystem für eine Anzeigevorrichtung, das umfaßt: eine Vielzahl von aneinandergrenzenden, länglichen Linsenelementen (17, 17a), die einen elliptischen Querschnitt besitzen und im wesentlichen parallel zueinander angeordnet sind, um partiell paralleles Licht bereitzustellen;
einen zur Lieferung von nicht-parallelem Licht an die Linsenelemente angeordneten Lichtkasten (11), wobei der Lichtkasten im Innern hoch und diffus reflektierend ist, der Lichtkasten mindestens eine Lichtquelle (12a, 12b) enthält, die in der Nähe einer Kante des Lichtkastens angeordnet ist, der Lichtkasten einen mit den Linsenelementen zusammenfallenden Opaklichtwerfer (13) besitzt, wobei der Lichtwerfer eine Vielzahl von länglichen, Licht übertragenden Schlitzen (19) enthält, die im wesentlichen parallel zu den Linsenelementen angeordnet und in Bezug auf die optischen Achsen der Linsenelemente zentriert sind, um einzeln das nicht-parallele Licht von dem Lichtkasten an die Linsenelemente zu übertragen, **gekennzeichnet durch** erste (26R), zweite (26G) und dritte (26B) verschieden gefärbte Filter, die aufeinanderfolgend in den Schlitzen gemäß einem Wiederholungsmuster angeordnet sind.

Revendications

1. Système d'éclairage pour un dispositif d'affichage qui comprend une matrice de petites lentilles sensiblement circulaires (27) disposées de manière à fournir de la lumière partiellement collimatée ; une boîte à lumière (11) disposée de manière à fournir de la lumière non collimatée aux dites petites lentilles, ladite boîte à lumière étant fortement et de façon diffuse, réfléchissante intérieurement, ladite boîte à lumière logeant au moins une source lumineuse (12a, 12b) disposée à proximité d'un bord de ladite boîte lumineuse, ladite boîte lumineuse ayant un réflecteur opaque à la lumière (13) qui coïncide avec lesdites petites lentilles, ledit réflecteur comprenant une matrice d'ouvertures transmettant la lumière (28) centrées par rapport aux axes optiques des dites petites lentilles de manière à transmettre individuellement de la lumière non collimatée à partir de ladite boîte à lumière auxdites petites lentilles ; lesdites ouvertures ayant un rayon sensiblement inférieur au rayon desdites lentilles caractérisé par des premiers (26R), seconds (26G) et troisièmes (26B) filtres d'interférence, disposés en séquence dans lesdites ouvertures selon une configuration répétitive, lesdits premiers filtres transmettant la première couleur primaire de la lumière (R) et réfléchissant la seconde (G) et troisième (B)

couleurs primaires de la lumière en retour dans ladite boîte ; les seconds filtres transmettant la seconde couleur primaire de la lumière et réfléchissant les deux autres couleurs primaires de la lumière en retour dans ladite boîte et ledit troisième filtre transmettant la troisième couleur primaire de la lumière et réfléchissant les deux autres couleurs primaires de la lumière en retour dans ladite boîte.

2. Système d'éclairage selon la revendication 1, caractérisé en ce que lesdites petites lentilles circulaires (27) forment une lentille intégrale (14b) comportant une surface lisse (18) en regard de ladite boîte à lumière (11) et ledit réflecteur (13) est fixé de façon permanente à ladite surface lisse.

3. Système d'éclairage selon la revendication 2, caractérisé en ce que lesdites ouvertures (28) sont décalées de ladite surface lisse (18).

4. Système d'éclairage selon la revendication 3, caractérisé en ce que le rayon desdites ouvertures (28) est inférieur à sensiblement 15% du rayon des petites lentilles (27).

5. Système d'éclairage selon l'une quelconque des revendications 2 à 4, caractérisé en ce que ladite source lumineuse comprend au moins un tube allongé (12a, 12b) disposé sensiblement parallèle au bord de ladite boîte à lumière (11) et à l'extérieur de ladite lentille intégrale (14b).

6. Système d'éclairage pour un dispositif d'affichage comprenant une pluralité de petites lentilles allongées juxtaposées (17, 17a) ayant une section droite elliptique, disposées sensiblement parallèlement les unes aux autres de manière à fournir de la lumière partiellement collimatée ;
une boîte à lumière (11) disposée de manière à fournir de la lumière non collimatée aux dites petites lentilles, ladite boîte à lumière logeant au moins une source lumineuse (12a, 12b) disposée à proximité d'un bord de ladite boîte à lumière, ladite boîte à lumière ayant un réflecteur opaque à la lumière (13) coïncidant avec lesdites petites lentilles, ledit réflecteur comportant une pluralité de fentes allongées transmettant la lumière (19) disposées sensiblement parallèlement aux dites petites lentilles et centrées par rapport aux axes optiques desdites petites lentilles de manière à transmettre individuellement de la lumière non collimatée à partir de ladite boîte à lumière aux dites petites lentilles ;
caractérisé par des premiers (26R), seconds (26G) et troisièmes (26B) filtres colorés de façon différente, disposés en séquence dans lesdites fentes selon une configuration répétitive.

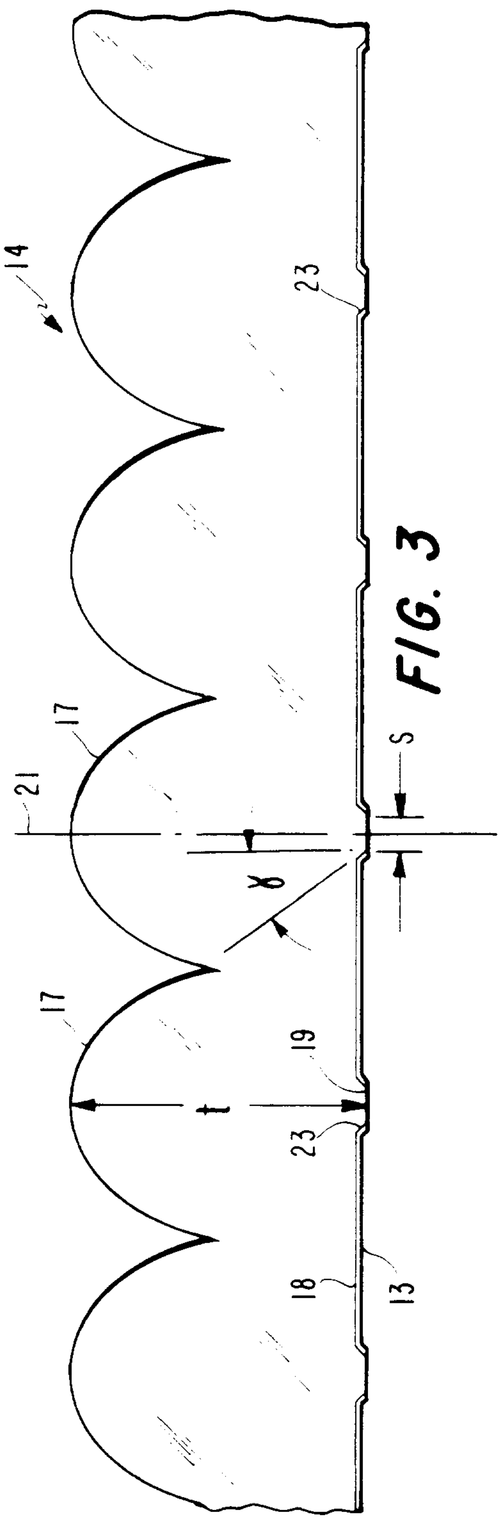


FIG. 3

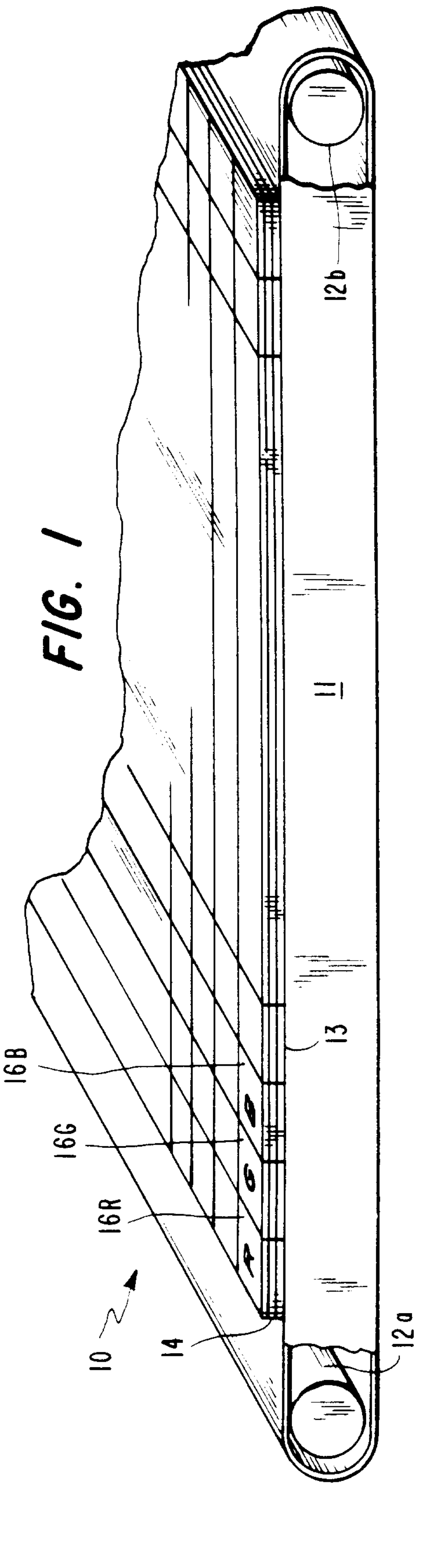


FIG. 1

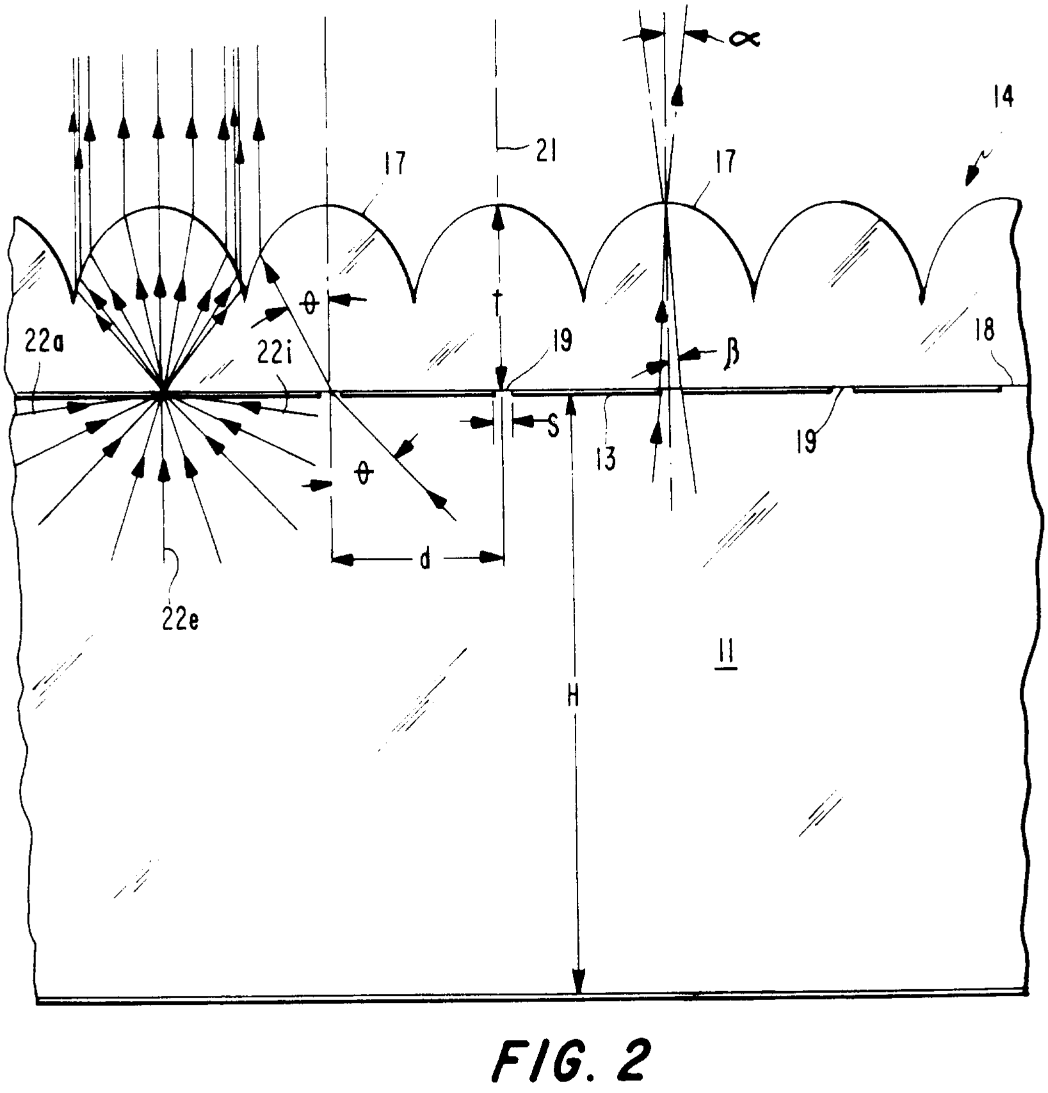


FIG. 2

FIG. 4

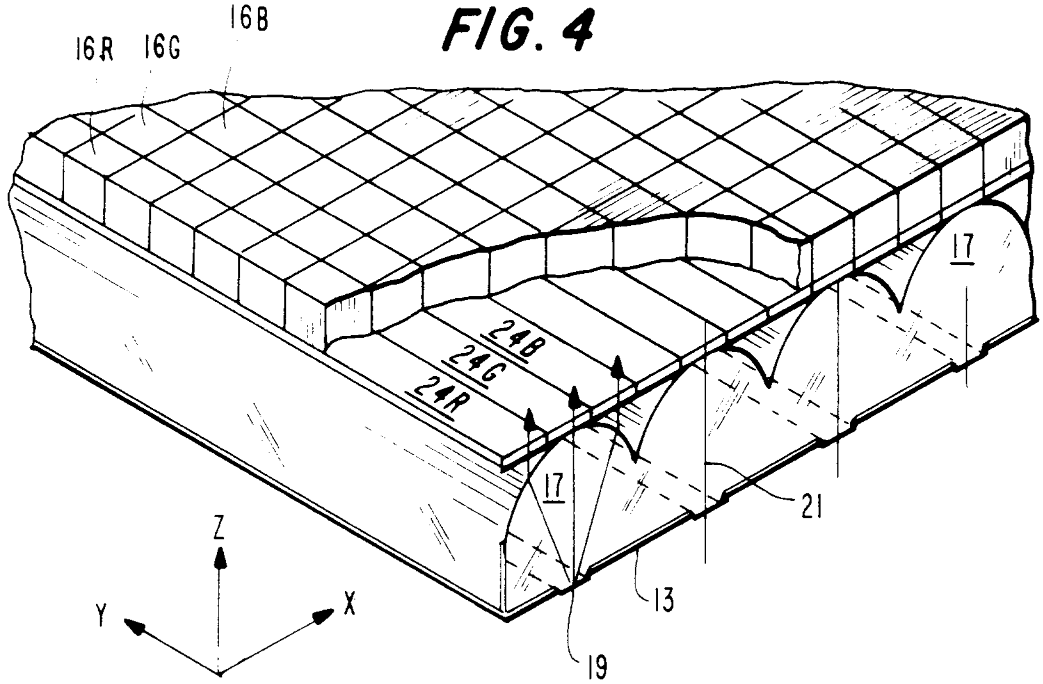
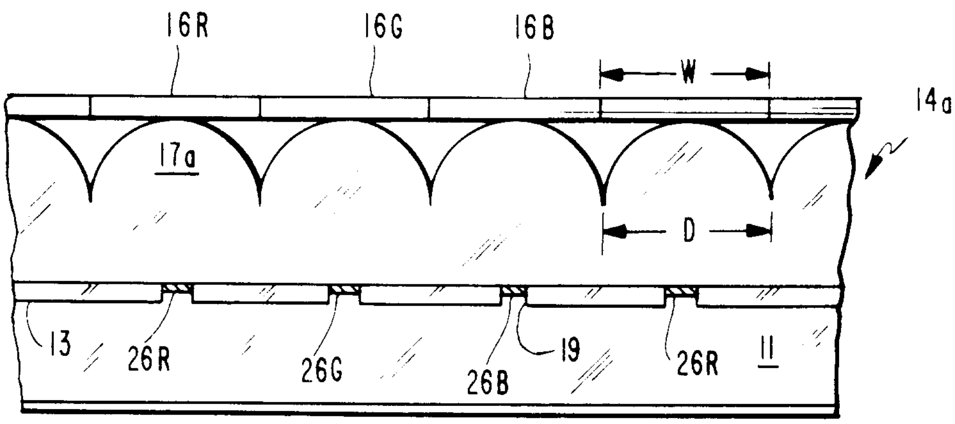

16R
16G
16B
24B
24G
24R
17
17
21
13
19
Z
Y
X

FIG. 5


16R
16G
16B
W
14a
17a
D
13
26R
26G
26B
19
26R
11

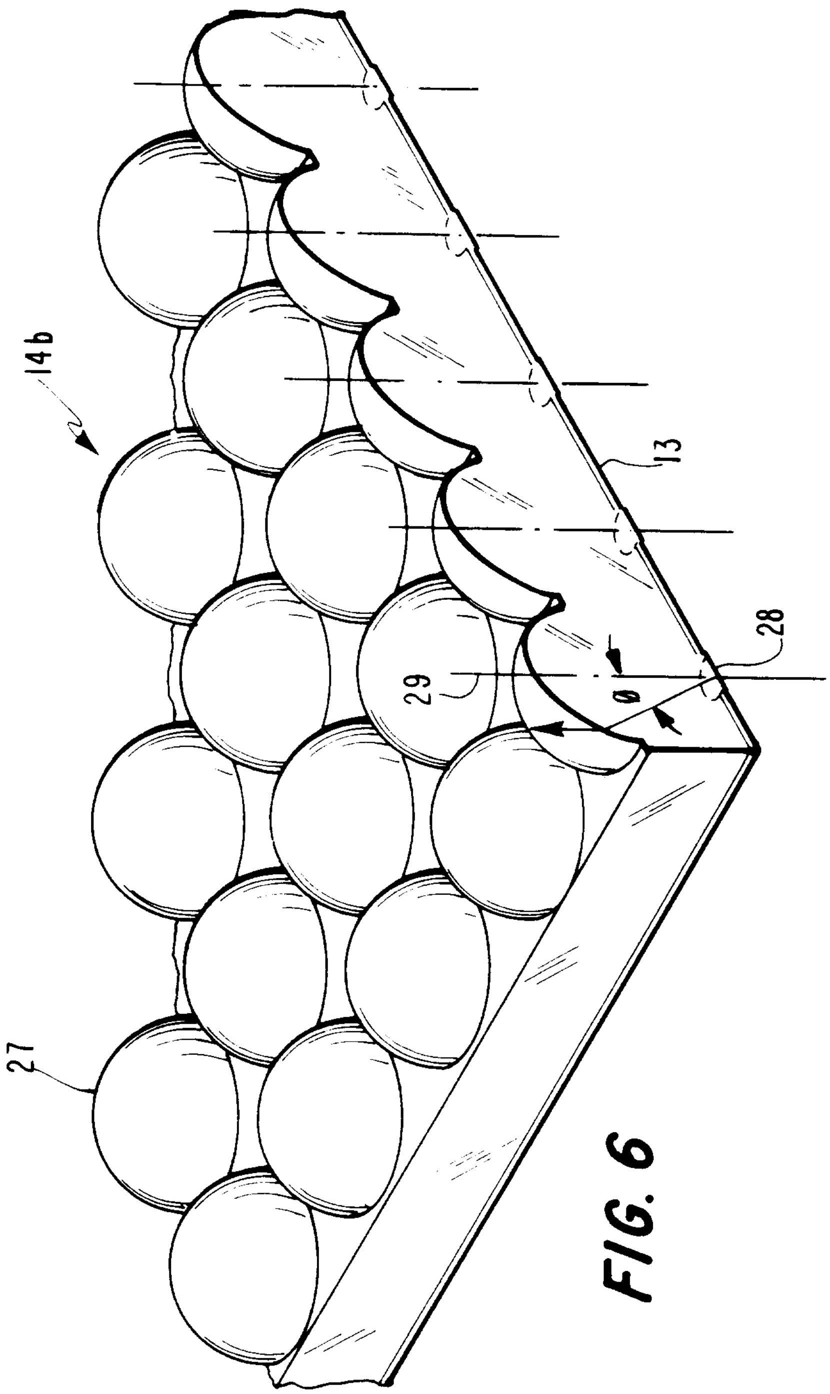


FIG. 6

FIG. 7